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Wind Turbine Syndrome

A Report on a Natural Experiment

Nina Pierpont, MD, PhD

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The Report, for clinicians

Abstract

This report documents a consistent and often debilitating complex of symptoms experienced by adults and children while living near large industrial wind turbines (1.5–3 MW). It examines patterns of individual susceptibility and proposes pathophysiologic mechanisms. Symptoms include sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering that arise while awake or asleep.

The study is a case series of 10 affected families, with 38 members age <1 to 75, living 305 m to 1.5 km (1000 to 4900 ft) from wind turbines erected since 2004. All competent and available adults and older teens completed a detailed clinical interview about their own and their children's symptoms, sensations, and medical conditions a) before turbines were erected near their homes, b) while living near operating turbines, and c) after leaving their homes or spending a prolonged period away.

Statistically significant risk factors for symptoms during exposure include pre-existing migraine disorder, motion sensitivity, or inner-ear damage (pre-existing tinnitus, hearing loss, or industrial noise

exposure). Symptoms are not statistically associated with pre-existing anxiety or other mental health disorders. The symptom complex resembles syndromes caused by vestibular dysfunction. People without known risk factors are also affected.,

The proposed pathophysiology posits disturbance to balance and position sense when low frequency noise or vibration stimulates receptors for the balance system (vestibular, somatosensory, or visceral sensory, as well as visual stimulation from moving shadows) in a discordant fashion. Vestibular neural signals are known to affect a variety of brain areas and functions, including spatial awareness, spatial memory, spatial problem-solving, fear, anxiety, autonomic functions, and aversive learning, providing a robust neural framework for the symptom associations in Wind Turbine Syndrome. Further research is needed to prove causes and physiologic mechanisms, establish prevalence, and explore effects in special populations, including children. This and other studies suggest that safe setbacks will be at least 2 km (1.24 mi), and will be longer for larger turbines and in more varied topography.

Introduction and Background

Policy initiatives in the United States and abroad currently encourage the construction of extremely large wind-powered electric generation plants (wind turbines) in rural areas. In its current format, wind electric generation is a variably regulated, multi-billion-dollar-a-year industry. Wind turbines are now commonly placed close to homes. Usual setbacks in New York State, for example, are 305–457 m (1000–1500 ft) from houses.[1] Developer statements and preconstruction modeling lead

[1] Town of Ellenburg, NY, wind law: 1000 ft (305 m); Town of Clinton, NY, wind law: 1200 ft (366 m); Town of Martinsburg, NY, wind law: 1500 ft (457 m). For other examples in and outside NY State, see *Wind Energy Development: A Guide for Local Authorities in New York*, New York State Energy Research and Development Authority, October 2002, p. 27. http://text.nyserda.org/programs/pdfs/windguide.pdf.

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communities to believe that disturbances from noise and vibration will be negligible or nonexistent.[2–4] Developers assure prospective communities that turbines are no louder than a refrigerator, a library reading room, or the rustling of tree leaves which, they say, easily obscures turbine noise.[5]

Despite these assurances, some people experience significant symptoms after wind turbines are placed in operation near their homes. The purpose of this study is to establish a case definition for the consistent, frequently debilitating, set of symptoms

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[2] "The GE 1.5 MW wind turbine, which is in use in Fenner, New York, is generally no louder than 50 decibels (dBA) at a distance of 1,000 feet (the closest we would propose siting a turbine to a residence). Governmental and scientific agencies have described 50 dBA as being equivalent to a 'quiet room.' Please keep in mind that these turbines only turn when the wind blows, and the sound of the wind itself is often louder than 50 dBA. Our own experience, and that of many others who live near or have visited the Fenner windfarm, is that the turbines can only be heard when it is otherwise dead quiet, and even then it is very faint, especially at a distance." Letter from Noble Environmental Power, LLC, to residents of Churubusco (Town of Clinton), New York, 7/31/2005.

[3] "Virtually everything with moving parts will make some sound, and wind turbines are no exception. However, well-designed wind turbines are generally quiet in operation, and compared to the noise of road traffic, trains, aircraft, and construction activities, to name but a few, the noise from wind turbines is very low. . . . Today, an operating wind farm at a distance of 750 to 1,000 feet is no noisier than a kitchen refrigerator or a moderately quiet room." Facts about wind energy and noise. American Wind Energy Association, August 2008, p. 2. www.windturbinesyndrome.com/?p=698.

[4] "In general, wind plants are not noisy, and wind is a good neighbor. Complaints about noise from wind projects are rare, and can usually be satisfactorily resolved." Facts about wind energy and noise. American Wind Energy Association, August 2008, p. 4. www.windturbinesyndrome.com/?p=698.

[5] "Outside the nearest houses, which are at least 300 metres away, and more often further, the sound of a wind turbine generating electricity is likely to be about the same level as noise from a flowing stream about 50–100 metres away or the noise of leaves rustling in a gentle breeze. This is similar to the sound level inside a typical living room with a gas fire switched on, or the reading room of a library or in an unoccupied, quiet, air-conditioned office. . . . Even when the wind speed increases, it is difficult to detect any increase in turbine sound above the increase in normal background sound, such as the noise the wind itself makes and the rustling of trees." Noise from wind turbines: the facts. British Wind Energy Association, August 2008. www.windturbinesyndrome.com/?p=698.

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experienced by people while living near wind turbine installations, and to place this symptom complex within the context of known pathophysiology. A case definition is needed to allow studies of causation, epidemiology, and outcomes to go forward, and to establish adequate community controls.

This set of symptoms stands out in the context of noise control practice. George Kamperman, P.E., INCE Bd. Cert., past member of the acoustics firm Bolt, Beranek and Newman (USA), wrote, "After the first day of digging into the wind turbine noise impact problems in different countries, it became clear that people living within about two miles from 'wind farms' all had similar complaints and health problems. I have never seen this type of phenomenon [in] over fifty plus years of consulting on industrial noise problems. The magnitude of the impact is far above anything I have seen before at such relatively low sound levels. I can see the devastating health impact from wind turbine noise but I can only comment on the physical noise exposure. From my viewpoint we desperately need noise exposure level criteria."[6]

I named this complex of symptoms "Wind Turbine Syndrome" in a preliminary fashion in testimony before the Energy Committee of the New York State Legislature on March 7, 2006. My observation that people can feel vibration or pulsations from wind turbines, and find it disturbing, was quoted in the brief section, "Impacts on Human Health and Well-Being" in the report *Environmental Impacts of Wind-Energy Projects* of the National Academy of Science, published in May 2007. No other medical information was cited in this report. The authors asked for more information to better understand these effects.[7]

[6] George Kamperman, personal communication, 2/21/2008. See www.kamperman.com/index.htm.

[7] National Research Council. 2007. *Environmental Impacts of Wind-Energy Projects*. The National Academies Press, Washington, DC. 185 pp, p. 109.

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Debates about wind turbine–associated health problems have been dominated to date by noise control engineers, or acousticians, which is problematic in part because the acoustics field at present is dominated by the wind turbine industry,[8] and in part because acousticians are not trained in medicine. A typical approach to wind turbine disturbance complaints, world-wide, is *noise first, symptoms second*: if an acoustician can demonstrate with noise measurements that there is no noise considered significant in a setting, then the symptoms experienced by people in that setting can be, and frequently are, dismissed. This has been the experience of seven of the ten families in this study in the United States, Canada, Ireland, and Italy.[9] At least one developer has put forward the hypothesis that a negative attitude or worry towards turbines is what leads people to be disturbed by turbine noise.[10]

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[8] George Kamperman, personal communication, 2/23/2008.

[9] A notable exception to this pattern is the physics research and modeling of GP van den Berg, who, as a graduate student and member of the Science Shop for Physics of the University of Groningen in the Netherlands, investigated noise complaints near a windplant and devised new models of atmospheric noise propagation to fit the phenomena he observed. References: 1) van den Berg, GP. 2004. Effects of the wind profile at night on wind turbine sound. J Sound Vib 277: 955–70; 2) van den Berg, GP. 2004. Do wind turbines produce significant low frequency sound levels? 11th International Meeting on Low Frequency Noise and Vibration and Its Control, Maastricht, Netherlands, August 30 to September 1, 8 pp.; 3) van den Berg, GP. 2005. The beat is getting stronger: the effect of atmospheric stability on low frequency modulated sound of wind turbines. J Low Freq Noise Vib Active Contr 24(1): 1–24; 4) van den Berg, GP. 2006. The sound of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise. PhD dissertation, University of Groningen, Netherlands. 177 pp. http://irs.ub.rug.nl/ppn/294294104

[10] "We often use the word 'noise' to refer to 'any unwanted sound.' It's true that wind turbines make sounds ... but whether or not those sounds are 'noisy' has a lot to do with who's listening. It's also worth noting that studies have shown [no references provided in source document] that a person's attitude toward a sound—meaning whether it's a 'wanted' or 'unwanted' sound—depends a great deal on what they think and how they feel about the source of the sound. In other words, if someone has a negative attitude to wind turbines, or is worried about them, this will affect how they feel about the sound. However, if someone has a positive attitude toward wind energy, it's very unlikely that the sounds will bother them at all." Wind fact sheet #5: Are modern wind turbines noisy? p. 2. Noble Environmental Power, LLC. www.windturbinesyndrome.com/?p=698.

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A reorientation is in order. If people are so disturbed by their headaches, tinnitus, sleeplessness, panic episodes, disrupted children, or memory deficits that they must move or abandon their homes to get away from wind turbine noise and vibration, then that noise and vibration is by definition significant, because the symptoms it causes are significant. The role of an ethical acoustician is to figure out what type and intensity of noise or vibration creates particular symptoms, and to propose effective control measures.

My study subjects make it clear that their problems are caused by noise and vibration. Some symptoms in some subjects are also triggered by moving blade shadows. However, I do not present or analyze noise data in this study, because noise is not my training. (Conversely, symptoms and disease are not the training of acousticians.) I focus on detailed symptomatic descriptions and statistical evaluation of medical susceptibility factors within the study group. Correlating the noise and vibration characteristics of the turbine-exposed homes with the symptoms of the people in the homes is an area ripe for collaboration between medical researchers and independent noise control engineers.

Other than articles on the Internet, there is currently no published research on wind turbine–associated symptoms. A UK physician, Dr. Amanda Harry, whose practice includes patients living near wind turbines, has published online the results of a checklist survey, documenting specific symptoms among 42 adults who identified themselves to her as having problems while living 300 m to 1.6 km (984 ft to 1 mi) from turbines.[11] She found a high prevalence of sleep disturbance, fatigue, headache, migraine, anxiety, depression, tinnitus, hearing loss, and palpitations. Respondents described a similar set of symptoms and many of the same experiences that

[11] Harry, Amanda. 2007. Wind turbines, noise, and health. 32 pp. www.windturbinenoisehealthhumanrights.com/wtnoise_health_2007_a_barry.pdf

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I document in this report, including having to move out of their homes because of symptoms. Respondents were mostly older adults: 42% were age 60 or older, 40% age 45–60, 12% age 30–45, and 5% age 18–30. A biomedical librarian, Barbara Frey, working with this physician and others, has published online a compilation of other personal accounts of symptoms and sensations near wind turbines.[12] These also mirror what I document.

Robyn Phipps, PhD, a New Zealand scientist specializing in health in indoor environments, systematically surveyed residents up to 15 km (9.3 mi) from operating wind turbine installations, asking both positive and negative questions about visual, noise, and vibration experiences.[13] All respondents (614 or 56% of the 1100 households to whom surveys were mailed) lived at least 2 km (1.24 mi) from turbines, with 85% of respondents living 2–3.5 km (1.24–2.2 mi) from turbines and 15% farther away. Among other questions, the survey asked about unpleasant physical sensations from turbine noise, which were experienced by 2.1% of respondents, even at these distances. Forty-one respondents (6.7%) spontaneously telephoned Dr. Phipps to tell her more than was asked on the survey about their distress due to turbine noise and vibration, nearly all (39) with disturbed sleep.[14] Symptoms were not further differentiated in this study, but clearly may occur at distances even greater than 2 km (1.24 mi) from turbines.

Published survey studies have examined residents' reactions to wind turbines relative to modeled noise levels and visibility of

[12] Frey, Barbara J, and Hadden, Peter J. 2007. Noise radiation from wind turbines installed near homes: effects on health. 137 pp. www.windturbinenoisehealthhumanrights.com/wtnhhr_june2007.pdf.

[13] Phipps, Robyn. 2007. Evidence of Dr. Robyn Phipps, in the matter of Moturimu wind farm application heard before the Joint Commissioners, March 8–26. Palmerston North, New Zealand. 43 pp. www.wind-watch.org/documents/wp-content/uploads/phipps-moturimutestimony.pdf.

[14] Phipps 2007.

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turbines in Sweden[15–17] and the Netherlands.[18–20] The study in the Netherlands included questions on health, though not of sufficient power to make any statements on health other than the correspondence between sleep disturbance and modeled noise (see below, Discussion). Both sets of studies, the Swedish and Dutch, have findings that could contribute to the rational setting of noise limits near wind turbines (see Discussion).

With regard to official opinion, the National Academy of Medicine in France recommended in 2005 that industrial wind turbines be sited at least 1.5 km (0.93 mi) from human habitation due to health effects of low frequency noise produced by the turbines.[21]

Current wind turbines have three airfoil-shaped rotor blades attached by a hub to gears and a generator, which are housed in a bus-sized box (nacelle) at the top of a nearly cylindrical, hollow

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15 Pedersen E, Persson Waye K. 2004. Perceptions and annoyance due to wind turbine noise: a dose-response relationship. J Acoust Soc Am 116(6): 3460–70.

16 Pedersen E. 2007. Human response to wind turbine noise: perception, annoyance and moderating factors. PhD dissertation, Occupational and Environmental Medicine, Department of Public Health and Community Medicine, Göteborg University, Göteborg, Sweden. 86 pp.

17 Pedersen E, Persson Waye K. 2007. Wind turbine noise, annoyance and self-reported health and wellbeing in different living environments. Occup Environ Med 64(7): 480–86.

18 Pedersen E, Bouma J, Bakker R, van den Berg GP. 2008. Response to wind turbine noise in the Netherlands. J Acoust Soc Am 123(5): 3536 (abstract).

19 van den Berg GP, Pedersen E, Bakker R, Bouma J. 2008. Wind farm aural and visual impact in the Netherlands. J Acoust Soc Am 123(5): 3682 (abstract).

20 van den Berg GP, Pedersen E, Bouma J, Bakker R. 2008. Project WINDFARMperception: visual and acoustic impact of wind turbine farms on residents. Final report, June 3. 63 pp. Summary: http://umcg.wewi.eldoc.ub.rug.nl/FILES/root/Rapporten/2008/WINDFARMperception/WFp-final-summary.pdf. Entire report: https://dspace.hh.se/dspace/bitstream/2082/2176/1/WFp-final.pdf.

21 Académie nationale de médecine de France. 2006. "Le retentissement du fonctionnement des éoliennes sur la santé de l'homme, le Rapport, ses Annexes et les Recommandations de l'Académie nationale de médecine, 3/14/2006." 17 pp. www.academie-medecine.fr/sites_thematiques/EOLIENNES/chouard_rapp_14mars_2006.htm.

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steel tower. The nacelle is rotated mechanically to face the blades into the wind. The blades spin upwind of the tower. The tower is anchored in a steel-reinforced concrete foundation. Turbine heights in this study were 100 to 135 m (328 to 443 ft) with hub heights 59 to 90 m (194 to 295 ft) and blade lengths 33 to 45 m (108 to 148 ft). Individual turbine powers were 1.5 to 3 MW. Clusters contained from 8 to 45 individual turbines (see Table 1B).

In this study, participants from all families described good and bad symptomatic periods correlated with particular sounds from the turbine installations, rate of turbine spin, or whether the turbines were turned towards, away from, or sideways relative to their homes. All participants identified wind directions and intensities that exacerbated their problems and others that brought relief. Many subjects described a quality of invasiveness in wind turbine noise, more disturbing than other noises like trains. Some stated that the noise wouldn't sound loud to people who did not live with it, or that noises described with benign-sounding terms like "swish" or "hum" were in reality very disturbing. Several were disturbed specifically by shadow flicker, which is the flashing of light in a room as the slanting sun shines through moving turbine blades, or the repetitive movement of the shadows across yards and walls. (These observations are documented in the narrative data of the CASE HISTORIES.)

Wind turbines generate sound across the spectrum from the infrasonic to the ultrasonic,[22] and also produce ground-borne or seismic vibration.[23] "In the broadest sense, a sound wave is any disturbance that is propagated in an elastic medium, which may be

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[22] van den Berg 2004a.

[23] Styles P, Stimpson I, Toon S, England R, and Wright M. 2005. Microseismic and infrasound monitoring of low frequency noise and vibrations from wind farms: recommendations on the siting of wind farms in the vicinity of Eskdalemuir, Scotland. 125 pp. www.esci.keele.ac.uk/geophysics/News/windfarm_monitoring.html

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a gas, a liquid, or a solid. Ultrasonic, sonic, and infrasonic waves are included in this definition. . . . Sonic waves [are] those waves that can be perceived by the hearing sense of the human being. Noise is defined as any perceived sound that is objectionable to a human being."[24]

Following standard usage in noise literature, I use the word *vibration* to refer to disturbances in solid media, such as the ground, house structures, or the human body. When air-borne sound waves of particular energy (power) and frequency meet a solid object, they may set the object vibrating. Conversely, a vibrating solid object, such as the strings on a violin, can create sound waves in air. There is energy transfer in both directions between air-borne or fluid-borne sound waves and the vibration of solids. When I talk about noise and vibration together, I am referring to this continuum of mechanical energy in the air and solids.

Energy in either form (sound or vibration) can impinge on the human body, and there may be multiple exchanges between air and solids in the path between a source and a human. The tissues of humans and other animals are semi-liquid to varying degrees, and have fluid-filled and air-filled spaces within them, as well as solid structures like bones. As an example of such energy transfer, a sound wave in the air, encountering a house, may set up vibrations in the structure of the house. These vibrations, in walls or windows, may set up air pressure (sound) waves in rooms, which can in turn transmit mechanical energy to the tympanic membrane and middle ear, to the airways and lungs, and to body surfaces. Alternatively, vibrations in house structures or the ground may transmit energy directly to the body by solid-to-solid contact and be conducted through the body by bone conduction.

[24] Beranek LL. 2006. Basic acoustical quantities: levels and decibels. Chapter 1 in *Noise and Vibration Control and Engineering: Principles and Applications*, ed. Ver IL, Beranek LL, pp. 1–24. John Wiley & Sons, Hoboken, NJ. p. 1.

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All parts of the body (and indeed all objects) have specific resonance frequencies, meaning that *particular frequencies or wavelengths of sound will be amplified in that body part.*[25] If the wavelength of a sound or its harmonic matches the dimensions of a room, it may set up standing waves in the room with places where the intersecting, reverberating sound waves reinforce each other. Resonance also occurs inside air-filled body cavities such as the lungs, trachea, pharynx, middle ear, mastoid, and gastrointestinal tract. The elasticity of the walls and density of the contents of these spaces affect the dynamics of sound waves inside them. The orbits (bones surrounding the eyes) and cranial vault (braincase) are also resonance chambers, because of the lower density of their contents compared to the bones that surround them. There are also vibratory resonance patterns along the spine (which is elastic), including a resonance involving the movement of the head relative to the shoulders. Von Gierke[26,27] and Rasmussen[28] have described the resonant frequencies of different parts of the human body.

Noise intensity is measured in decibels (dB), a logarithmic scale of sound pressure amplitude. Single noise measurements or integrated measurements over time combine the energies of a range of frequencies into a single number, as defined by the filter or weighting network used during the measurement. The A-weighting

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[25] Hedge, Alan. 2007. Department of Design and Environmental Analysis, Cornell University. Syllabus/lecture notes for DEA 350: Whole-body vibration (January), found at http://ergo.human.cornell.edu/studentdownloads/DEA325pdfs/Human%20Vibration.pdf

[26] von Gierke HE, Parker DE. 1994. Differences in otolith and abdominal viscera graviceptor dynamics: implications for motion sickness and perceived body position. Aviat Space Environ Med 65(8): 747–51.

[27] von Gierke HE. 1971. Biodynamic models and their applications. J Acoust Soc Am 50(6): 1397–413.

[28] Rasmussen G. 1982. Human body vibration exposure and its measurement. Bruel and Kjaer Technical Paper No. 1, Naerum, Denmark. Abstract: Rasmussen G. 1983. Human body vibration exposure and its measurement. J Acoust Soc Am 73(6): 2229.

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network is the most common in studies of community noise. It is designed to duplicate the frequency response of human hearing for air-borne sounds entering through the outer and middle ear. A-weighting slightly augments the contributions of sounds in the 1000 to 6000 Hz range (from C two octaves above middle C, key 64 on the piano, to F# above the highest note on the piano), and progressively reduces the contributions of lower frequencies below about 800 Hz (G-G# 1½ octaves above middle C, keys 59–60). At 100 Hz, where the human inner-ear vestibular organ has a peak response to vibration[29] (G-G# 1½ octaves below middle C, keys 23–24), A-weighting reduces sound measurement by a factor of 1000 (30 dB). At 31 Hz (B, the second-to-bottom white key, key 3), A-weighting reduces sound measurement by a factor of 10,000 (40 dB). Thus A-weighting preferentially captures the high sounds used in language recognition, to which the human cochlea and outer and middle ear are indeed very sensitive, but reduces the contribution of mid- and lower-range audible sounds, as well as infrasound (defined as 20 Hz and below).

Linear (lin) measurements use no weighting network, so the frequency responses are limited by other aspects of the system, such as microphone sensitivity. Linear measurements may capture low frequency sounds but are not standardized—different sound level meters yield different results. As a result, the standardized and commonly available C-weighting network is preferred for measuring environmental noise with low frequency components, such as noise from wind turbines. The C-weighting network has a flat response (meaning that it does not reduce or enhance the contributions of different frequencies) over the audible frequency range and a well-defined decreasing response below 31 Hz.

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[29] Todd NPMc, Rosengren SM, Colebatch JG. 2008. Tuning and sensitivity of the human vestibular system to low-frequency vibration. Neurosci Lett 444: 36–41.

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One third (1/3) octave band studies are used to describe sound pressure levels by frequency, and are presented as a graph rather than a single number. One third (1/3) octave bands can also be measured linearly or with weighting networks.

Methods

The study design is a case series of affected families, interviewed by telephone. I used a broad-based, structured interview including a narrative account, symptom checklist, past medical and psychiatric history, personal and social history, selected elements of family history, and review of systems. This is the "history" in the standard physician's "history and physical," with specific questions oriented towards the problems in question. The core of the syndrome consists of symptoms such as sleep disturbance, headache, tinnitus, dizziness, nausea, anxiety, concentration problems, and others which are typically diagnosed by medical history more than physical exam.

Limited medical records were provided by the adults of families A and B (A1, A2, B1, B2) and by a young man in family C (C4). I requested records for all families through F, but since no more were forthcoming, I stopped asking, and pursued those parts of the study not dependent on physical examination or test results, and for which I had a uniform study tool, the interview.

The study design includes comparison groups in two ways: 1) I obtained information for each symptom before exposure, during exposure, and away from or after the end of exposure, so that each subject acted as his or her own control in the "natural experiment" of living in a home under a certain set of conditions, having wind turbines added to those conditions, and then moving or going away and again experiencing an environment without turbines. Subjects also noted how their symptom intensity varied in concert

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with the type and loudness of noise, the direction turbine blades were turned, the rate of spin, or the presence or absence of shadow flicker. A positive symptom is one that emerged from the within-subject comparison as distinctly worse during exposure than before or after (generally both). For example, a subject was considered to have headaches due to turbine exposure only if his (her) headaches were more frequent, severe, or longer-lasting during turbine exposure than his own headaches before being exposed to turbines and after ending the exposure. 2) I obtained information on all household members, not only the most affected, so that I could compare more affected to less affected subjects, all of whom were exposed, to evaluate individual risk factors with regard to age, sex, and underlying health conditions.

Families were selected to conform to all of the following: 1) severity of symptoms of at least one family member; 2) presence of a "post-exposure" condition, in which the family had either left the affected home or spent periods of time away; 3) quality of observation, memory, and expression, so that interviewed people were able to state clearly, consistently, and in detail what had happened to them under what conditions and at what time (all but one individual were native English speakers); 4) residence near recently erected turbines (placed in operation 2004–2007); 5) short time span between moving out and the interview, if exposure had already ended (six weeks was the maximum); and 6) family actions in response to turbine noise showing how serious and debilitating the symptoms were (moving out, purchasing a second home, leaving home for months, renovating house, sleeping in root cellar).

Most families who met these criteria and were willing to be interviewed lived outside the United States. In the course of the study, I received direct evidence that participation by Americans was limited by non-medical factors such as turbine leases or neighbor contracts prohibiting criticism, court decisions restricting

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criticism of turbine projects, and community relationships. The same factors are likely, in future, to affect other studies of wind turbine noise effects in the United States, with the potential to introduce significant bias into any population-based study.

Moving is an economic hardship for all the families in the study. All own (or owned) their homes, but only three of the eight families who have left their homes have sold them: one to the utility operating the turbines, one to a buyer introduced to the family by the turbine owner, and one to an independent buyer. Three families do not have their homes for sale because the properties include farmland which they farm or lease out. These families have rented additional houses in nearby villages for living and sleeping, though they can ill afford it. The remaining two families who have left their homes are trying to sell the homes, but have not been successful. One of the two families that have not moved is trying to sell their home so they can move. The tenth family has not moved and is not at this point trying to sell the home.

Though not by design, each case household consisted of a married couple or a married couple with children. One family included an older parent. I interviewed both members of each couple except for one man with dementia, and I interviewed the older parent together with her daughter-in-law. I directly interviewed three out of the four subjects in the 16- to 21-year-old age group; the fourth did not make himself available. Child data are otherwise derived from the parent interviews.

I audio-recorded the interviews for the first two families (C and D, in 2006) as I was developing the interview protocol, but after that noted answers directly on an interview form, writing down distinctive or critical observations and symptom descriptions verbatim. Because of subject time constraints, I also audio-recorded the final family (J, in 2008). Subjects who were recorded

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gave their permission verbally at the beginning of the interview. I made a confidentiality statement and informed subjects that they would have the opportunity to review the data presented about them prior to publication. Follow-up interviews were done with families C, D, and G. Other families have kept in touch by email and telephone about further developments. All ten families have reviewed the information presented about them and signed permission for anonymous publication.

I use simple statistical tests (2x2 χ^2) to examine associations among symptoms and between pre-existing conditions and symptoms during exposure.[30] Degrees of freedom (df) are 2 for all the χ^2 results in this report. Children were excluded from the analysis of adult symptoms if no child younger than a certain age had the symptom in question. Study children were categorized into developmental-age blocks (see Table 1C). When I excluded children from an analysis, I excluded all the children in that age block and below. Excluding children from adult symptom analyses avoided inflating the no symptom/absent pre-existing condition box of the 2x2 χ^2 contingency tables, which could artificially increase the χ^2 value.

Results

I interviewed 23 adult and teenage members of 10 families, collecting information on all 38 adult, teen, and child family members. One family member was a baby born a few days before the family (A) moved out, so there are no data for this child on sleep or behavior during exposure (which was in utero). Thus the sample size of subjects for whom we have information about experiences or behavior during exposure is 37.

[30] Sokal RR, Rohlf FJ. 1969. *Biometry.* W. H. Freeman, San Francisco.

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Residence status and family composition are detailed in Table 1A; turbine, terrain, and house characteristics in Table 1B; and the age and sex distribution of subjects in Table 1C. Twenty subjects were male and 18 female, ranging in age from <1 to 75. Seventeen subjects were age 21 and below, and 21 subjects were age 32 and above. There is a gap in the 20's and a preponderance of subjects in their 50's. Wind turbine brands to which study subjects were exposed included Gamesa, General Electric, Repower, Bonus (Siemens), and Vestas.

Individual accounts of baseline health status and pre-exposure, during exposure, and post-exposure symptoms or absence of symptoms are presented in the CASE HISTORIES for families A through J, with a separate sub-table (A1, A2, A3, etc.) for each individual. I encourage the reader to read these, because they highlight the before-during-after comparisons for each person, show how the symptoms fit together for individuals, reveal family patterns, and provide subjects' own words for what they feel and detect. When individuals are referred to in the text, the letter and number in parentheses (e.g., A1, C2) refers to the CASE HISTORY table in which that subject's information is found.

Baseline conditions

Eight adult subjects had current or history of serious medical illness, including lupus (1), breast cancer (2), diabetes (1), coronary artery disease (2), hypertension (1), atrial fibrillation with anticoagulation (1), Parkinson's disease (1), ulcer (1), and fibromyalgia (2). Two were male (age 56–64) and six female (age 51–75). Other past and current medical illnesses are listed in Table 2. Four subjects smoked at the beginning of exposure, and five others had smoked in the past (Table 2). There were no seriously ill children in the sample.

Seven subjects had histories of mental health disorders including depression, anxiety, post-traumatic stress disorder (PTSD), and

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bipolar disorder. Three were male (age 42–56) and four female (age 32–64). One of these men (age 56) also had Alzheimer's disease. There were no children with mental health disorders or developmental disabilities in this sample.

Eight subjects had pre-existing migraine disorder (including two with previous severe sporadic headaches that I interpreted as migraine). Four were male (age 19–42) and four female (age 12–42). An additional seven subjects, age <1 to 17, were children of migraineurs who had not experienced migraines themselves at baseline.

Eight subjects had permanent hearing impairments, defined subjectively or objectively, including mild losses, losses limited to one ear, or impairments of binaural processing. Six were male (age 32–64) and two female (age 51–57).

Six subjects had continuous tinnitus or a history of multiple, discrete episodes of tinnitus prior to exposure. Four were male (age 19–64) and two female (age 33–57).

Twelve subjects had significant previous noise exposure, defined as working in noisy industrial or construction settings; working on or in a diesel boat, truck, bus, farm equipment, or aircraft; a military tour of duty; or operating lawn mowers and chain saws for work. Not included were home or sporadic use of lawn mowers and chain saws, commuting by train or airplane, urban living in general, or playing or listening to music. Nine of the noise-exposed subjects were male (age 19–64) and three female (age 33–53).

Eighteen subjects were known to be motion sensitive prior to exposure, as defined by carsickness as a child or adult, any episode of seasickness, or a history of two or more episodes of vertigo. Ten were male (age 6–64) and eight female (age 12–57).

Table 1A: Cases: personal attributes

Case	Country	# in household	# interviewed	Ages†	Head of household occupations	Residence status
A	Canada	4	2	33, 32, 2½, 2 months	Fisherman, accountant	Moved to a rented house in nearby village 6 months after renovating their own home, which is vacant. Land they own continues to be leased to a farmer.
B*	Canada	3	3	55, 53, 19	Fisherman, homemaker	Moved to a rented house in nearby village. Home is vacant. Land they own, which has been in the family for over a century, continues to be leased to a farmer.
C	Canada	8	3	45, 42, 21, 19, 15, 12, 9, 5	Fisherman, homemaker	Family divided and moved in with extended family members. Home, built 24 years before by husband on land in family for over a century, is vacant and for sale.
D	Canada	2	2	64, 64	Retired/disabled, home health aide	Occupied home, purchased second house in village 25 miles away during study. Sold home and moved after study completed.
E	Canada	2	1	56, 56	Retired/disabled, teacher	Moved to a newly purchased house in a nearby village after turbine utility bought their home and property.

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Case	Country	# in household	# interviewed	Ages†	Head of household occupations	Residence status
F	UK	4	4	<u>51</u>, <u>42</u>, <u>17</u>, <u>75</u>**	Farmer, nurse midwife	Rented house in nearby village and continue to use farm and home office during day.
G	Ireland	6	2	<u>35</u>, <u>32</u>, 6, 5, 2, 8 months	Computer programmer, homemaker	Under pressure from family, turbine owner arranged purchase at 30% below pre-turbine value.
H	Ireland	3	2	<u>57</u>, <u>52</u>, 8	Milk truck driver, homemaker	Family occupies home. Significant renovations made in attempt to exclude noise.
I	Italy	2	2	<u>59</u>, <u>52</u>	Professional gardener, teacher	Occupied newly built home during study but wife spent months away due to symptoms. Moved out after study completed, leaving home vacant and for sale.
J	USA	4	2	<u>49</u>, <u>47</u>, 13, 8	Physician, nurse	Family occupies home.

*Families A and B are related and own separate homes on the same property.
**Grandmother living in different house on same property did not move away.
†Underlined ages indicate interviewees.

1803

Table 1B: Cases: physical attributes

Case	Distance to closest turbine	# turbines	MW per turbine	Year placed in operation	Hub height	Total height	Terrain	Configuration of turbines	House construction
A	1000 m (3281 ft)	10	3	2007	90 m	135 m	Hilly with rocky ridges	10 in line point at house at hub level	Wood frame
B*	1000 m (3281 ft)	10	3	2007	90 m	135 m	Hilly with rocky ridges	10 in line point at house at hub level	Wood frame
C	305 m (1000 ft)	17	1.8	2004–05	80 m	125 m	Rocky peninsula	On three sides	Wood frame
D	548 m (1798 ft)	22	1.8	2006	78 m	117 m	Flat farmland	Group on one side	Wood frame
E	423 m (1388 ft)	45	1.5	2006	87 m	120 m	Flat farmland, swamp	On three sides	Brick with stone front
F	930 m (3051 ft)	8	2	2006	59 m	100 m	Flat farmland	5 in line point at house	Brick on cement slab
G	596 m (1955 ft)	32	3	2006	80 m	125 m	Rocky hills	Above house on three sides	Stone cottage, walls 60 cm thick
H	1500 m (4921 ft)	11	2.3	2005	80 m	121 m	Rocky hills	Above house on three sides	Stone cottage, cement slab
I	875 m (2871 ft)	10	2	2006	78 m	121 m	Rocky hills	Across valley at higher elevation	Stone and brick, walls 50 cm thick
J	732 m (2400 ft)	40	2	2007	80 m	123 m	Ridges and valleys	6 in L-shape above house on two sides	Wood frame

*Families A and B are related and own separate homes on the same property.

1804

Table 1C: Cases: demographics

Age	Male	Female	Total
<1	1	1	2
1–3	1	1	2
4–6	2	1	3
7–11	3	0	3
12–15	1	2	3
16–21	2	2	4
22–29	0	0	0
30–39	2	2	4
40–49	3	2	5
50–59	4	5	9
60–69	1	1	2
70–79	0	1	1
Totals	**20**	**18**	**38**

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The subjects' baseline conditions are summarized in Table 3.

Seven subjects had a remembered history of a single concussion, and none had a history of a more severe head injury. Six were male (age 19–59) and one female (age 12). I did not collect information on whiplash injury.

Core symptoms

Core symptoms are defined as 1) common and widely described by study participants, 2) closely linked in time and space to turbine exposure, and 3) amenable to diagnosis by medical history. Core symptoms include sleep disturbance, headache, tinnitus, other ear and hearing sensations, disturbances to balance and equilibrium, nausea, anxiety, irritability, energy loss, motivation loss, and disturbances to memory and concentration.

An additional core symptom is a new type of internal or visceral sensation which has no name in the medical lexicon. Subjects struggled to explain these sensations, often apologizing for how strange their words sounded. A physician subject called it "feeling jittery inside" or "internal quivering." Other subjects chose similar words, while others talked about feeling pulsation or beating inside. The physical sensations of quivering, jitteriness, or pulsation are accompanied by acute anxiety, fearfulness, or agitation, irritability, sleep disturbance (since the symptom arises during sleep or wakefulness), and episodes of tachycardia. I call this sensation and accompanying symptoms *Visceral Vibratory Vestibular Disturbance* (VVVD). It is described further below.

Core symptoms are closely correlated with exposure, including being at home, the direction and strength of the wind, whether turbines are facing the home, and the presence of moving blade shadows. Core symptoms all resolve immediately or within hours away from the turbines, with the exception of disturbances of

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concentration and memory, which resolved immediately in some cases or improved over weeks to months in others.

Core symptoms are summarized in Table 3.

Sleep disturbance. Thirty-two subjects (17 males age 2–64 and 15 females age 2–75) had disturbed sleep. Types of sleep disturbance included: difficulty getting to sleep, frequent or prolonged awakening by turbine noise, frequent or prolonged awakening by awakened children, night terrors (both 2½-year-olds, B3 and G5), nocturnal enuresis (one 5-year-old girl, G4), nocturia (six women age 42–75 and one man age 64; B2, C2, E2, F2, F4, H2, D1), excessive movement during sleep (one 8-year-old boy, H3), excessive nighttime fears (two 5-year-olds, a girl and a boy, C8 and G4), and abrupt arousals from sleep in states of fear and alarm (four women age 42–57; C2, F2, H2, I2). Other adults, though not fearful when they woke up, awoke with physical symptoms similar to their daytime symptoms of anxiety/agitation/internal quivering (three men age 42–64 and two women age 32–53; D1, F1, J1, B2, G2). Four people slept well, including the one infant (G6), a 19-year-old woman (B3), a 47-year-old woman (J2) and her 8-year-old son (J4). It was unclear whether a 56-year-old man with dementia, bipolar disorder, Parkinson's disease, and disturbed sleep at baseline (E1) slept worse than usual or not.

With three exceptions, all types of sleep disturbance resolved immediately whenever subjects slept away from their turbine-exposed homes, including the adult nocturia and the 5-year-old's nocturnal enuresis. A 49-year-old man with a pre-existing sleep disturbance (J1) took two nights to get back to his baseline, and a 45-year-old man (C1) and a 42-year-old man (F1) did not improve all the way to baseline; this was thought to be due to coexisting depression after abandoning their homes.

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Table 2: Past and current serious medical illness

	Adult (>22 yo) (n=21)		Child/youth (0–21 yo) (n=17)	
	Male	Female	Male	Female
Breast cancer		2		
Skin cancer	1			
Lupus		1		
Diabetes	1			
Polycystic ovarian syndrome		1		
Coronary artery disease	1	1		
Atrial fibrillation with anticoagulation		1		
Other arrhythmias	1	1		
Hypertension—present		1		
Hypertension—past or pregnancy		2		
Parkinson's disease	1			
Diplopia		1		
Renal function impairment	1			
Ulcer—past	1			
Gastroesophageal reflux	2	3		
Irritable bowel syndrome	1	1		
Fibromyalgia		2		
Osteoarthritis	1	1		
Back pain	2	1	1	
Other joint pain	1			
Asthma	2	2		1
Eczema		1	1	
Frequent/chronic otitis media—present			1	1
Frequent/chronic otitis media—past		1	2	1
Smoking—present	3	1		
Smoking—past	3	1	1	

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Table 3: Baseline conditions and core symptom occurrence*

	Total	Male	Ages	Female	Ages	N**	% of sample
Baseline Conditions							
Serious medical illness†	8	2	56–64	6	51–75	38	21
Mental health disorders‡	7	3	42–56	4	32–64	34	21
Migraine disorder	8	4	19–42	4	12–42	34	24
Hearing impairments	8	6	32–64	2	51–57	34	24
Pre-existing tinnitus	6	4	19–64	2	33–57	24	25
Previous noise exposure	12	9	19–64	3	33–53	24	38
Motion sensitivity	18	10	6–64	8	12–57	34	53
Core Symptoms							
Sleep disturbance	32	17	2–64	15	2–75	36	89
Headache	19	8	6–55	11	12–57	34	56
VVVD◊	14	6	32–64	8	32–75	21	67
Dizziness, vertigo, unsteadiness	16	7	19–64	9	12–64	27	59
Tinnitus	14	9	19–64	5	33–57	24	58
Ear pressure or pain	11	6	2–25	5	19–57	36	30
External auditory canal sensation	5	2	42–55	3	52–75	34	15
Memory and concentration deficits (salient+mild/vague)	28	15	6–64	13	5–57	30	93
Irritability, anger	28	15	2–64	13	2–64	37	76
Fatigue, loss of motivation	27	14	2–64	13	2–75	36	75

*A symptom during exposure is defined as distinctly worse for that individual during exposure compared to before and/or after exposure.
**N=number of subjects in which it was possible to know about the condition or symptom, given age and other specific limitations (see p. 41 and subsequent text).
†See p. 42 and Table 2.
‡See p. 42 and subsequent text for definitions of this and other conditions and symptoms.
◊Visceral Vibratory Vestibular Disturbance: See pp. 48 and 55ff.

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Headache. Nineteen subjects experienced headaches that were increased in frequency, intensity, and/or duration compared to baseline for that person. Eight were male (age 6–55) and eleven female (age 12–57). Eight had pre-existing migraine (C2, C3, C4, C5, C6, F1, G1, G2). Two women (one a migraineur, one not; C2, E2) had severe headaches provoked by shadow flicker. All other exposure-related headaches were triggered by noise alone. Recovery from headaches generally took several hours after the exposure ended.

Headache risk factors were examined in a subset of the study group that included all subjects age 5 and older (N=34), since the younger children in the study (age <1 to 2) were not reliable sources of information on headache. The occurrence of unusually severe or frequent headaches during exposure was significantly associated with pre-existing migraine disorder (χ^2 = 8.26, p = 0.004). All 8 subjects with pre-existing migraine experienced headaches that were unusually intense, frequent, or prolonged compared to their baseline headaches. Of the 26 subjects without pre-existing migraine, 11 also experienced unusual or severe headaches during exposure. Two of these were children of migraineurs not known to have migraine themselves (a girl age 17 and a boy age 6; F3, G3). All children or teens (through age 21) who had headaches during exposure were migraineurs or children of migraineurs.

Once migraine was factored out as a risk factor, 9 of 17 subjects over age 22 without a history of migraine still had headaches of increased intensity, duration, or frequency during exposure to turbines. I found no significant correlation within this group between headache and the presence of serious underlying medical illness (χ^2 = 0.486, p = 0.486), present or past mental health disorder (χ^2 = 0.476, p = 0.490), tinnitus or hearing loss at baseline, motion sensitivity at baseline, or tinnitus, disequilibrium, or VVVD during exposure.

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In summary, a little more than half (19) of the 34 study participants age 5 and older experienced unusually severe headaches during exposure. Migraine was a statistically significant risk factor but was present in fewer than half (8) of the 19 subjects with worsened headache. Children and teens up to age 21 with headaches either had known migraine or were the children of migraineurs. Nine of the 19 headache subjects were adults without clear risk factors, showing that while people with migraine are more likely to have headaches of unusual intensity, duration, or frequency around turbines, so can other adults without identified risk factors.

Ears, hearing, and tinnitus. Fourteen subjects (nine males age 19–64 and five females age 33–57) experienced tinnitus that was new or worse in severity or duration than at baseline. For two men (age 55 and 64; B1, D1), the tinnitus at times interfered with their ability to understand conversation. Four of the 14 subjects experienced particularly disturbing kinds of tinnitus or noise which was perceived to be inside the head (two men age 42, 55, and two women age 52, 57; B1, F1, H2, I2). This sensation was painful for two subjects. Tinnitus tended to resolve over several hours after exposure ended.

Tinnitus risk factors were examined in subjects age 16 and older, since the youngest person with tinnitus was in this age group. The subject with dementia (E1) was excluded, since there was no information on his hearing status or tinnitus. Sample size was 24 subjects. The occurrence of new or worsened tinnitus in the presence of turbines was significantly correlated with previous noise exposure ($\chi^2 = 6.17$, $p = 0.013$), tinnitus prior to exposure ($\chi^2 = 5.71$, $p = 0.017$), and baseline hearing loss ($\chi^2 = 4.20$, $p = 0.040$). New or worsened tinnitus during exposure was strongly correlated with ear popping, ear pressure, or ear pain during exposure ($\chi^2 = 7.11$, $p = 0.008$), and weakly correlated with dizziness/disequilibrium during exposure ($\chi^2 = 3.70$, $p = 0.054$). Tinnitus

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during exposure did not show a significant relationship with pre-existing migraine or motion sensitivity, or with headache or VVVD during exposure.

Eleven subjects during exposure experienced ear popping, ear or mastoid area pressure, ear pain without infection, or a sensation that the eardrum was moving but not producing a sensation of sound (six males age 2–55 and five females age 19–57). The 2½-year-old (A3) pulled on his ears and got cranky repeatedly at the same time as his grandmother's (B2) exacerbations of headache, tinnitus, and ear pain. Correlations with tinnitus during exposure are described above. Five subjects experienced tickling, blowing, or undefined sensations in the external auditory canal, or increased wax production (two men age 42, 55, and three women age 52–75).

Individual subjects noticed changes in their hearing or auditory processing. A 33-year-old woman (A2) had progressively worsening tinnitus during her five months of exposure. After she moved away, the tinnitus resolved and she noticed she had a new difficulty understanding conversation in a noisy room, now needing to watch the speaker's face carefully. Her son (A3, the 2½-year-old who pulled on his ears and got cranky, above) did not confuse sounds before exposure, but began to do so during exposure, and continued to do so at the time I interviewed his mother six weeks after the exposure ended. The child's language development was otherwise good. A 42-year-old woman (C2) had tinnitus throughout her 21-month exposure period without subjective hearing changes. After she moved and the tinnitus resolved, she noted hyperacusis. A 32-year-old woman (G2) experienced hyperacusis during exposure, but no tinnitus. The hyperacusis resolved after the family moved.

Balance and equilibrium. Sixteen subjects (seven males age 19–64 and nine females age 12–64) experienced disturbance to their balance or sense of equilibrium during exposure, describing

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dizziness, light-headedness, unsteadiness, or spinning sensations. One of them, a 42-year-old woman (C2), described how a friend, sitting next to her in her turbine-exposed home, remarked how her (C2's) eyes appeared to be bouncing back and forth (nystagmus). Ten of these 16 subjects also experienced nausea during exposure to turbines, during or separate from dizziness. No children under the age of 12 had symptoms of dizziness, disequilibrium, or nausea during exposure, except for the usual nausea of acute gastrointestinal and other infections.

Risk factors for dizziness/disequilibrium in the presence of turbines were analyzed using subjects age 12 and up, since this was the youngest age child with this type of symptom. The subject with Parkinson's disease and dementia (E1) was excluded because his baseline balance problems and inability to express himself made it hard for his wife (the informant) to tell if he had worsened symptoms during exposure or not. The remaining sample was 27 subjects. Disequilibrium during exposure was significantly correlated with headaches during exposure ($\chi^2 = 5.08$, $p = 0.024$) and baseline motion sensitivity ($\chi^2 = 4.20$, $p = 0.040$). Disequilibrium during exposure is weakly correlated with tinnitus during exposure ($\chi^2 = 3.70$, $p = 0.054$). (Inspection of the data shows that these are primarily ataxic (unsteady) subjects.) Dizziness/disequilibrium during exposure was not correlated with VVVD or ear popping/pressure/pain during exposure, pre-existing migraine disorder, previous noise exposure, or prior tinnitus or hearing loss.

Internal quivering, vibration, or pulsation. Eleven adult subjects described these uncomfortable, unfamiliar, and hard-to-explain sensations:

- Dr. J (J1, age 49) described "internal quivering" as part of the "jittery feeling" he has when the turbines are turning fast.

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- Mrs. I (I2, age 52) said the noise inside her house is "low, pulsating, almost a vibration," not shut out by earplugs. She gets a sensation inside her chest like "pins and needles" and chest tightness on awakening at night to noise. "It affects my body—this is the feeling I get when I say I'm agitated or jittery. It's this that gives me pressure or ringing in my ears." "A feeling someone has invaded not only my health and my territory, but my body."
- Mrs. H (H2, age 57) described a pulsation that prevented sleep from the "unnatural" noise from the turbines.
- Mr. G (G1, age 35) described feeling disoriented and "very strange" in certain parts of the house where he could "feel rumbling." If he did not move quickly away from these locations, the feeling would progress to nausea. He described the noise as "at times very invasive. Train noise has a different quality, and is not invasive."
- Mrs. G (G2, age 32) felt disoriented, "light-headed," dizzy, and nauseated in her garden and in specific parts of the house where she detected vibration. She felt her body vibrating "inside," but when she put her hand on walls, windows, or objects, they did not seem to be vibrating.
- Mrs. F (F2, age 51) described a physical sensation of noise "like a heavy rock concert," saying the "hum makes you feel sick."
- Mrs. E (E2, age 56), when supine, felt a "ticking" or "pulsing" in her chest in rhythm with the audible swish of the turbine blades. She interpreted this as her "heart synchronized to the rhythm of the blades," but there is no information (such as a pulse rate from the wrist at the same time) to determine whether this was true or not, or whether she detected a separate type of pulsation. Mrs. E could make these sensations go away by getting up and moving around, but they started again when she lay back down.

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- Mr. D (D1, age 64) felt pulsations when he lay down in bed. In addition, "When the turbines get into a particular position (facing me), I get real nervous, almost like tremors going through your body . . . it's more like a vibration from outside . . . your whole body feels it, as if something was vibrating me, like sitting in a vibrating chair but my body's not moving." This occurs day or night, but not if the turbines are facing "off to the side."
- Mr. C (C1, age 45) felt pulsations in his chest that would induce him to hold his breath, fight the sensation in his chest, and not breathe "naturally." Chest pulsations interrupted his sleep and ability to read. He also described a sensation of "energy coming within me . . . like being cooked alive in a microwave."
- Mrs. B (B2, age 53) described her breath being "short every once in a while, like [while] falling asleep, my breathing wanted to catch up with something."
- Mr. B (B1, age 55) had two episodes of feeling weight on his chest while lying down, which resolved when he stood up. Other than this, he experienced the invasive quality of the noise in his head and ears: "That stuff [turbine noise] doesn't get out of your head, it gets in there and just sits there—it's horrible."

Agitation, anxiety, alarm, irritability, nausea, tachycardia, and sleep disturbance are associated with internal vibration or pulsation:

- Dr. J's (J1, age 49) "jittery" feeling includes being "real anxious," irritable, and "no fun to be around." He interrupts outdoor and family activities to sequester himself in his well-insulated house. When the turbine blades are spinning fast and he detects certain types of noise and vibration as he arrives home from work, he gets queasy and loses his appetite. He awakens from sleep with the "jittery" feeling and tachycardia, and may need to go downstairs to a cot in the 55-degree root cellar (the

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only place on his property where he cannot hear or feel the turbines) to be able to fall back to sleep. He often takes deep breaths or sighs when in the "jittery" state.

- Mrs. I (I2, age 52) describes episodic "queasiness and nausea" with loss of appetite, "trembling in arms, legs, fingers," "strong mental and physical agitation," and frequent unexpected crying. On noisy nights she awakens after four hours of sleep, weeping in the night. "When I wake up, [there is] more a feeling of pressure and tightness in my chest; it makes me panic and feel afraid." It is "a startling sort of waking up, a feeling there was something and I don't know what it was." Once she awoke thinking there had been an earth tremor (there had not), and twice she has awakened with tachycardia, the "feeling your heart is beating very fast and very loud, so I can feel the blood pumping." Feelings of panic keep her from going back to sleep.
- Mrs. H (H2, age 57) awakens 5–6 times per night with a feeling of fear and a compulsion to check the house. She describes it as a "very disturbed sort of waking up, you jolt awake, like someone has broken a pane of glass to get into the house. You know what it is but you've got to check it—go open the front door—it's horrific." She finds it hard to fall back to sleep and describes herself as irritable and angry, shouting more at her family members.
- Mr. G (G1, age 35) described the noise outside his home and the noise that awakened him at night as "stressful."
- Mrs. G (G2, age 32) was, during exposure, irritable, angry, and worried about the future and her children. She awoke often at night because her children woke up, when she cared for their fears, mentioning none of her own.
- Mrs. F (F2, age 51) described a "feeling of unease all the time." At night she startles awake with heart pounding, a feeling of

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fear, and a compulsion to check the house. The feeling of alarm keeps her from being able to go back to sleep.

- Mrs. E (E2, age 56) did not express anxiety or fear, but she awakened repeatedly at night and was unable to get back to sleep on nights when the turbines were facing the house.
- Mr. D (D1, age 64) described how he has to "calm down" from the "tremor." If outside, "I come in, sit down in my chair and try to calm myself down. After an episode like that, I'm real tired." Mood has worsened with increased anger, frustration, and aggression. Tachycardia accompanies the "tremor" at times: "My heart feels like it's starting to race like crazy and I have these tremors going through my body." Mr. D pants or hyperventilates when the tremor and tachycardia occur, and consciously slows his breathing when calming down.
- Mr. C (C1, age 45) was unable to rest, relax, or recuperate in his home, where his body was "always in a state of defense." He had to drive away in his car to rest.
- Mrs. B (B2, age 53) became "upset and in a turmoil" when her symptoms worsened, leaving her house and tasks repeatedly to get relief.
- Mr. B (B1, age 55) described stress, "lots, pretty near more'n I could take, it just burnt me, the noise and run-around." He was prescribed an anxiolytic, and spent more time at the shore in his fishing boat for symptom relief.

The internal quivering, vibration, or pulsation and the associated complex of agitation, anxiety, alarm, irritability, tachycardia, nausea, and sleep disturbance together make up what I refer to as *Visceral Vibratory Vestibular Disturbance* (VVVD). Fourteen adult subjects (six men age 35–64 and eight women age 32–75) had VVVD during exposure, including the eleven quoted above and Mr. F (F1, age 42), Mrs. F Senior (F4, age 75), and Mrs. C (C2,

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age 42). Mr. I (I1, age 59) had partial symptoms, with an urge to escape, noise-induced nausea, and sleep disturbance, but no feeling of internal movement. VVVD resolves immediately upon leaving the vicinity of the turbines, when the turbines are still and silent, and under favorable weather conditions at each locality.

Because VVVD is in part a panic attack, accompanied by other physical and mental symptoms, I examined the relationships among VVVD and panic disorder, other mental health diagnoses, and other risk factors. The sample for this analysis was 21 adults ages 22 and above (since the study had no participants age 22–29, this is the same for this study as starting with the age group of the youngest symptomatic subjects, who were 32).

No study subjects had pre-existing panic disorder or previous isolated episodes of panic, so there was no correlation between pre-existing panic and VVVD. Seven subjects had mental health disorders either at the time turbines started up near their homes (two subjects) or in the past (five subjects), including depression, anxiety, post-traumatic stress disorder (PTSD), and bipolar disorder. There was no correlation between current or past mental health disorder and VVVD ($\chi^2 = 0.429$, $p = 0.513$). There was, however, a highly significant correlation between VVVD and motion sensitivity ($\chi^2 = 7.88$, $p = 0.005$).

There was also a moderately significant correlation between VVVD and headaches during exposure ($\chi^2 = 4.95$, $p = 0.026$). There was no correlation between VVVD and dizziness or tinnitus during exposure, or between VVVD and pre-existing migraine, tinnitus, or hearing loss.

Concentration and memory. Twenty of the 34 subjects age 4 and up (eleven males age 6–64 and nine females aged 5–56) had salient problems with concentration or memory during exposure

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to wind turbines, compared to pre- and/or post-exposure. This is a conservative count, including only subjects whose accounts included specific information on decline in school and homework performance (for children and teens) or details on loss of function for adults. Eight other subjects had some disturbance to concentration and memory, but symptoms were milder or the descriptions more vague (in their own or parents' accounts). Five other subjects, all older adults, noted no change compared to pre-existing memory problems. This leaves only one subject, a 19-year-old woman home from college and minimally exposed (B3), who did not have baseline deficits and was unaffected.

Pre-exposure cognitive, educational, and work accomplishments, specific difficulties related to concentration and memory during exposure, and degree and timing of post-exposure recovery are documented in the Case Histories for each individual, under "Cognition." Difficulties are often striking compared to the subject's usual state of functioning:

- Mr. A (A1, age 32), a professional fisherman with his own boat, who had an isolated difficulty with memory for names and faces prior to exposure, became routinely unable to remember what he meant to get when he arrived at a store, unless he had written it down.
- Mrs. B (B2, age 53), a homemaker, got confused when she went to town for errands unless she had written down what she was going to do, and had to return home to get her list. When interviewed six weeks after moving, she reported that she had improved to being able to manage three things to do without a list.
- Mr. C (C1, age 45) had to put reading aside because he could not concentrate whenever he felt pulsations.

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- Mrs. C (C2, age 42), a very organized mother of six who was "ready a month in advance for birthday parties" prior to exposure, became disorganized and had difficulty tracking multiple tasks at once, including while cooking, repeatedly boiling the water away from pots on the stove. She remarked, "I thought I was half losing my mind."
- Mr. D (D1, age 64), a disabled, retired industrial engineer, noticed progressive slowing of memory recall speed and more difficulty remembering what he had read.
- Mrs. E (E2, age 56), a retired teacher active in community affairs, could not spell, write emails, or keep her train of thought on the telephone when the turbine blades were turned towards the house, but was able to do these things when the blades were not facing the house.
- Mrs. F (F2, age 51), a nurse, child development specialist, midwife, and master's level health administrator, could not follow recipes, the plots of TV shows, or furniture assembly instructions during exposure.
- Mrs. G (G2, age 32), a well-organized mother of four, was forgetful, had to write everything down, could not concentrate, and could not get organized. She forgot a child's hearing test appointment. She did not have memory or concentration problems during a previous depression at age 18, and described her experience as "different this time."
- Mr. I (I1, age 59), a professional gardener, could not concentrate on his outdoor gardening and building tasks if the turbines were noisy, saying "after half an hour you have to leave, escape, close the door."
- Dr. J (J1, page 49), a physician, noticed marked concentration problems when he sat down to pay bills in a small home office with a window towards the turbines.

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Decline in school performance compared to pre-exposure, or marked improvement in school performance after moving away from turbines, was noted for 7 of the 10 study children and teens attending school (age 5–17; C7, F3, G3, G4, H3, J3, J4). For example:

- A 17-year-old girl (F3), a diligent student, was not concerned about the turbines and thought her parents were overdoing their concern until she unexpectedly did worse on national exams than the previous year, surprising her school, family, and self. At this point she began accompanying her parents to their sleeping house.
- A 9-year-old boy (C7), whose schoolwork was satisfactory without need for extra help prior to exposure, failed tests, lost his math skills, and forgot his math facts. He could not maintain his train of thought during homework, losing track of where he was if he looked up from a problem.
- A 6-year-old boy (G3), described as an extremely focused child and advanced in reading prior to exposure, did not like to read during exposure. Two months post-exposure, now age 7, he would sit down to read on his own for an hour at a time, reading "quite a thick book" for his age.
- His 5-year-old sister (G4) had a short attention span prior to exposure. Her hearing loss due to bilateral chronic serous otitis media was thought to be interfering with schoolwork during exposure, and she repeatedly had tantrums over schoolwork at home during the exposure period. Two months after moving, despite no change in her ears (on a waiting list for pressure equalization tubes), she was more patient and could work longer on homework. Her mother noted that her "schoolwork has improved massively."
- An 8-year-old boy (H3) had an excellent memory and did well in reading, spelling, and math prior to exposure. During exposure he became resistant to doing homework, with tantrums, and

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his teacher told him he was not concentrating and needed to go to bed earlier.

In comparing the 20 subjects with salient concentration or memory changes to the 14 who had no change from baseline or vague/minimal difficulties, there are significant relationships with 1) baseline cognition, in that those without memory or concentration deficits at baseline are more likely to notice such deficits during exposure ($\chi^2 = 4.86$, $p = 0.027$), and 2) fatigue or loss of energy or enjoyment for usual activities during exposure ($\chi^2 = 5.61$, $p = 0.018$). There is no significant relationship between salient concentration or memory changes and pre-existing psychiatric diagnoses, migraine, motion sensitivity, or noise exposure, or between salient concentration or memory changes and headache, tinnitus, VVVD, or irritability during exposure.

In addition to the statistical association between fatigue and concentration disturbance, a number of subjects directly attributed their concentration problems to their sleep deprivation or disturbance. Several aspects of the data, however, suggest that additional factors may be involved.

First, one subject, Mrs. E (E2, age 56), could not do certain mental tasks requiring concentration when the turbines were turned towards her house, but could do them when the turbines were not turned towards the house. Mr. C (C1, age 45), Mr. I (I1, age 59), and Dr. J (J1, age 49) also had concentration problems closely linked in time and space to direct exposure to turbine noise.

Second, some of the problems described by subjects, such as Mrs. F (F2, age 51) and the members of families A and B, are more extreme than I expect from sleep deprivation. The degree of thinking dysfunction involved in not being able to follow a recipe or assemble a piece of furniture, in a woman both highly educated

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and involved in several practical professions (nursing and farming), does not match my expectation of sleep deprivation from the experience, for example, of both younger and older physicians, who often function under sleep deprivation.

Third, some subjects had concentration problems without obvious sleep problems. All four members of family J had concentration problems, but only Dr. J (J1, age 49) was sleep deprived. Mrs. J (J2, age 47) fell asleep easily and usually went back to sleep if awakened, but still had problems with memory and focus in her home activities that she had noticed and attempted to treat. Their 13-year-old son (J3) needed white noise or music to drown out turbine noise to fall asleep, but went to sleep promptly, slept through the night, and did not complain in the morning of being tired or having slept poorly. His school performance and his level of distractibility at home, however, were both markedly different than at baseline. The younger son, age 8 (J4), continued to sleep well, but still had a surprising decline in school performance, though milder and of shorter duration than his brother's.

Fourth, the problems with concentration and memory resolve on a different schedule from the turbine-related sleep problems. Sleep problems resolve immediately except when accompanied by persistent depression (C1, F1). Problems with concentration and memory frequently took longer to improve, even in the absence of depression. To study resolution, we need to look at subjects who have moved away from their exposed homes or spent a prolonged period away that included work (families A, B, C, E, F, and G, and Mrs. I), since vacations do not provide the same challenges to concentration and memory. Of these 23 subjects over age 4, 13 had salient difficulties with concentration or memory:

- Mr. A (A1, age 32) rated his memory as 85% at baseline, 2% during exposure, and 10% six weeks after moving away.

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- Mr. and Mrs. B (B1, B2, age 55 and 53) said their memories had partially recovered six weeks after moving.
- Mr. C (C1, now age 47), with continuing depression and ongoing exposure for house maintenance, noted 25 months after moving how bad his memory seemed.
- Mrs. C (C2, now age 44) felt she had recovered her memory and concentration 18 months after moving, despite ongoing stress from crowded living arrangements. Her affected son (now age 11, C7) had not completely recovered his school performance.
- Mrs. E (age 52) recovered immediately. She only experienced problems during exposure when the turbines were turned in a particular direction.
- Mr. and Mrs. F (F1, F2, ages 42 and 51) had moved away but still worked at their turbine-exposed home and farm during the day. Three months after they moved, both thought their concentration had improved, but not to baseline. Mr. F, with ongoing depression, did not perceive any memory recovery. I do not have information about their daughter's (F3, age 17) exam performance after moving.
- Mrs. G (G2, age 32) rated her memory as 10/10 at baseline, 2/10 during exposure, and 5/10 two months after moving away, at which point her depression was mostly resolved. Mrs. G's 5-year-old and 6-year-old children (G3, G4) showed marked improvements in concentration by two months after moving.

Only three subjects were clearly depressed during or after exposure. Mrs. G (G2, age 32) was becoming depressed at the time of the first (during exposure) interview. She remarked on the difference in her cognitive functioning between her current experience and a previous episode of depression at age 18, when she had no problem with her memory or concentration. Two other subjects, Mr. C (C1, age 45) and Mr. F (F1, age 42), developed depression after they had

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to abandon their homes, which was associated with prolonged memory difficulties. Both also had ongoing exposure.

Irritability and anger. Twenty-eight subjects (15 male age 2–64 and 13 female age 2–64) perceived themselves or were noted by parents to be more angry, irritable, easily frustrated, impatient, rude, defiant, or prone to outbursts or tantrums than at baseline. The adults were uniformly apologetic about their own irritability, and several described how careful they were to avoid acting irritable in their households. Four children (three boys age 8–9 and a girl age 5; C7, G3, H3, G4) were markedly frustrated over homework. The young children of family G quarreled and had tantrums incessantly, and the six children/young adults in family C became angry, prickly, moody, defiant, or prone to fights at school. In families with children, the breakdown in children's behavior, social coping skills, and school performance was one of the strongest elements propelling them to move.

Fatigue and motivation. Twenty-one subjects felt or acted tired, and 24 had problems with motivation for usual, necessary, or formerly enjoyable activities (27 combined, 14 male age 2–64 and 13 female age 2–75). Like concentration and memory, these symptoms undoubtedly have a relationship with sleep deprivation, but certain subjects described leaden feelings around turbines that resolved as soon as they left the vicinity, such as Mr. A (A1, age 32), who said, "You feel different up there: draggy, worn out before you even start anything.... It was a chore to walk across the yard." After driving an hour away to visit a family member, "I felt better all over, like you could do a cart wheel," and he felt well after moving.

When away from their turbine-exposed homes, most subjects recovered their baseline positive mood states, energy, and motivation immediately. Six adult subjects did not. These were Mr. B (B1, age 55), Mr. and Mrs. C (C1, C2, age 45 and 42), Mr. and

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Mrs. F (F1, F2, age 42 and 51), and Mrs. G (G2, age 32). By their own accounts, three (Mr. C, Mr. F, and Mrs. G) had unresolved or resolving depression. All but Mrs. G had ongoing anxiety and anger over abandoning their homes and their unresolved life situations.

Other symptom clusters and isolated problems

These symptoms and problems occurred in fewer subjects and typically require more than a medical history to diagnose. Several are exacerbations of pre-existing conditions with obvious connections to situations of high stress or stress hormone (epinephrine, cortisol) output (cardiac arrhythmias, hypertension, irritable bowel, gastroesophageal reflux, glucose instability). One is an extension of a core symptom (unusual migraine aura). Others may indicate different kinds of direct effects of noise on body tissues, as in the vibroacoustic disease model of noise effects (respiratory infections, asthma, clotting abnormalities),[31] or other types of secondary effects (asthma).[32]

Respiratory infection/inflammation cluster. Seven subjects had unusual or prolonged lower respiratory infections during exposure (A2, B1, C2, E2, F1, F3, F4), and two of these also had prolonged asthma exacerbations (F1, F3). These two, however, were also taking a lot of paracetamol (acetaminophen) for their turbine-associated headaches. Four subjects had unusually severe or prolonged middle ear problems (C7, F2, G3, G4).

[31] Castelo Branco and Alves-Pereira 2004.

[32] Beasley R, Clayton T, Crane J, von Mutius E, Lai CK, Montefort S, Stewart A; ISAAC Phase Three Study Group. 2008. Association between paracetamol use in infancy and childhood, and the risk of asthma, rhinoconjunctivitis, and eczema in children aged 6–7 years: analysis from Phase Three of the ISAAC programme. Lancet 372(9643): 1039–48.

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Cardiovascular cluster. Two subjects had exacerbations of pre-existing dysrhythmias (F1, J2). Two women had hypertension that increased during and after the exposure period, requiring medication after the end of exposure. Both still had considerable stress related to moving out and not being able to establish another regular home, and depressed husbands (C2, F2).

Gastrointestinal cluster. Four subjects had exacerbations of pre-existing gastroesophageal reflux (GER), ulcer, or irritable bowel, two with irritable bowel and upper gastrointestinal symptoms at the same time (D1, F1, F2, J2).

Arthralgia/myalgia cluster. One healthy 32-year-old woman (G2) noted pain in one elbow while in her exposed house. It resolved when she went away for vacations with her family, and recurred when she returned. It resolved quickly when the family moved away, even though she did lots of lifting during the move. A 57-year-old woman (H2) with lupus arthritis and fibromyalgia at baseline experienced painful exacerbations whenever she returned home, with return to baseline when away. A 56-year-old woman (E2) with fibromyalgia at baseline had exacerbations which resolved during times away from her exposed home and after moving.

Diabetes control. A 56-year-old man with Type II diabetes (E1), stable on oral medications and insulin before exposure, had marked glucose instability accompanied by visual blurring, retinal changes, and polyuria during exposure.

Anticoagulation. A 75-year-old woman with atrial fibrillation (F4) had stable INR values on 2–4 mcg warfarin daily for 10 years. By 16 months of exposure, her warfarin dose had been increased to 8–9 mcg daily in response to decreasing INR values.

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Ocular cluster. Three subjects exposed to the same turbines (two men age 32–55 and one woman age 53; A1, B1, B2) had ocular pain, pressure, and/or burning synchronously with headache and tinnitus. Mr. D (D1, age 64) had a painless retinal stroke, losing half the vision in his left eye. Mr. D had a normal CT scan of the brain and was examined by an ophthalmologist.

Complex migraine phenomena. A 19-year-old fisherman (C4) with migraine at baseline had complex visual symptoms with flashes in square patterns in one eye at a time (scintillating scotoma), evolving to blurring and visual loss for 30 seconds to 2 minutes, also in one eye at a time (amaurosis fugax), right more than left, repetitively during the last month of his 15–21 month exposure until 8–12 months after exposure ended, with a decrease in frequency by 7 months after moving out. These events happened at any time of day and rarely overlapped with headaches or tinnitus. He had normal ophthalmologic exams, normal MRI and MRA scans of the brain and associated arteries, and a normal evaluation for clotting abnormalities and vasculitis. The events resolved completely with normal vision. The same man experienced repetitive complex basilar migraines with aura after the first few months of his 15–21 month turbine exposure, involving daily bilateral paresis and paresthesias of his legs and occasional headache, tinnitus, and light-headedness. The leg symptoms resolved on the same schedule as the eye symptoms, though headaches and nausea continue to be triggered regularly by seasickness.

Discussion

The core symptoms of Wind Turbine Syndrome are sleep disturbance, headache, tinnitus, other ear and hearing sensations, disturbances to balance and equilibrium, nausea, anxiety, irritability, energy loss, motivation loss, disturbances to memory and concentration, and *Visceral Vibratory Vestibular Disturbance*

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(VVVD). Core symptoms are defined as common and widely described by study participants, closely linked in time and space to turbine exposure, and amenable to diagnosis by medical history. The latter was a particular requirement of this study. The subjects of this study had other types of health problems during exposure, discussed in "Other symptom clusters and isolated problems," but different types of study will be needed to find out if there is a link between these problems and wind turbine exposure.

The most distinctive feature of Wind Turbine Syndrome is the group of symptoms I call *Visceral Vibratory Vestibular Disturbance*. The adults who experience this describe a feeling of internal pulsation, quivering, or jitteriness, accompanied by nervousness, anxiety, fear, a compulsion to flee or check the environment for safety, nausea, chest tightness, and tachycardia. The symptoms arise day or night, interrupting daytime activities and concentration, and interrupting sleep. Wakefulness is prolonged after this type of awakening. Subjects observe that their symptoms occur in association with specific types of turbine function: the turbines turned directly towards or away from them, running particularly fast, or making certain types of noise. The symptoms create aversive reactions to bedroom and house. Subjects tend to be irritable and frustrated, especially over the loss of their ability to rest and be revitalized at home. Subjects with VVVD are also prone to queasiness and loss of appetite even when the full set of symptoms is not present.

There is no statistical association in this study between VVVD and pre-existing panic episodes (which occurred in none of the subjects) or other mental health disorders, such as depression, anxiety, bipolar disorder, or post-traumatic stress disorder. There is a highly significant association between VVVD and pre-existing motion sensitivity ($p = 0.005$).

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Headaches more frequent or severe than at baseline occurred in all migraineurs in the study, and all children with headaches in the study were migraineurs or the children of migraineurs. Non-migrainous adults also got severe headaches around turbines, and indeed about half the people with headache worse than baseline (9 out of 19) were adults without history of migraine. Pre-exposure migraine is a significant risk factor for more severe or frequent headaches during turbine exposure ($p = 0.004$), but does not account for all the cases of headache.

Tinnitus occurred as a migraine aura in three subjects, but statistically in the study group tinnitus was not significantly associated with pre-existing migraine disorder, but rather with sensations of ear popping, pressure, or pain during exposure ($p = 0.008$), previous industrial noise exposure ($p = 0.013$), past history of tinnitus ($p = 0.017$), baseline permanent hearing impairment ($p = 0.040$), and (weakly) with dizziness/disequilibrium during exposure ($p = 0.058$). Like the other core symptoms, tinnitus resolved or returned to baseline when subjects were away from turbines. Previous noise exposure, past tinnitus, and baseline hearing impairment all suggest prior damage to the cochlea as a risk factor. The co-occurring symptoms of ear popping, pressure, and pain during exposure suggest that tinnitus may be caused near turbines by transient alterations in inner-ear fluid pressures (perilymph or endolymph). The weak correlation between tinnitus and dizziness/disequilibrium suggests that the proposed pressure shift may concurrently affect vestibular organ function.

Visceral Vibratory Vestibular Disturbance (VVVD)

The work of Mittelstaedt on visceral detectors of gravity,[33,34] and

[33] Mittelstaedt H. 1996. Somatic graviception. Biol Psychol 42(1–2): 53–74.

[34] Mittelstaedt H. 1999. The role of the otoliths in perception of the vertical and in path integration. Ann N Y Acad Sci 871: 334–44.

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Balaban and others on balance-anxiety linkages,[35–39] opens a window on the VVVD symptom set. Balaban, a neuroscientist, has localized and described the neural connections among the vestibular organs of the inner ear, brain nuclei involved with balance processing, autonomic and somatic sensory inflow and outflow, the fear and anxiety associated with vertigo or a sudden feeling of postural instability, and aversive learning.[40] These form a coordinated, neurologically integrated system based in the parabrachial nucleus of the brainstem and an associated neural network.[41,42] Several aspects of this system need to be considered here.

First, there appear to be not three but four body systems for regulating balance, upright posture, and the sense of position and motion in space.[43,44] The first three systems are the eyes, the semicircular canals and otolith organs of the inner ear (vestibular organs), and somatic input from skin, skeletal muscles, tendons,

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[35] Balaban CD, Yates BJ. 2004. The vestibuloautonomic interactions: a teleologic perspective. Chapter 7 in *The Vestibular System*, ed. Highstein SM, Fay RR, Popper AN, pp. 286–342. Springer-Verlag, New York.

[36] Balaban CD. 2002. Neural substrates linking balance control and anxiety. Physiology and Behavior 77: 469–75.

[37] Furman JM, Balaban CD, Jacob RG. 2001. Interface between vestibular dysfunction and anxiety: more than just psychogenicity. Otol Neurotol 22(3): 426–27.

[38] Balaban CD. 2004. Projections from the parabrachial nucleus to the vestibular nuclei: potential substrates for autonomic and limbic influences on vestibular responses. Brain Res 996: 126–37.

[39] Halberstadt A, Balaban CD. 2003. Organization of projections from the raphe nuclei to the vestibular nuclei in rats. Neuroscience 120(2): 573–94.

[40] Balaban and Yates 2004.

[41] Balaban CD, Thayer JF. 2001. Neurological bases for balance-anxiety links. J Anx Disord 15: 53–79.

[42] Balaban 2002.

[43] Mittelstaedt 1996.

[44] Mittelstaedt 1999.